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Influence of soil tillage and soil compaction on microarthropods in agricultural land

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Summary. Samples were taken from plots in an agricultural research area where the soil was mechanically compacted by wheeling. The soil compaction was achieved using graded wheel loadings on a wheel loader with 4 wheels on 2 axis: 0 t; 2 × 2.5 t; 6 × 5.0 t (wheeling frequency × wheel load). The soil tillage was conventional and separated into a deep tilled part (250 mm) and a shallow tilled part (120 mm). Collembola and mites dominated the microarthropod community followed by Pauropoda and beetle larvae. Mites were most abundant. The population size of the microarthropods decreased with increasing soil compaction. The total number of soil microarthropods increased from March to May. After this seasonal peak, the abundance decreased until the last sampling date in August before harvest. The abundance development during the growing season was hampered by soil compaction. The consequences of compaction were more evident in the deep tilled than in the shallow tilled plots. Collembola were more sensitive to soil compaction than mites. Only in shallow tilled plots did the microarthropod populations recover during one season. Furthermore, the vertical distribution of the microarthropods depended on soil tillage and compaction.

Key words: Microarthropods, Collembola, mites, soil tillage, soil compaction

Introduction

The problem of soil compaction caused by agricultural traffic endangers soil health. Soane & van Ouwerkerk (1994) summarized this economic and environmental problem by explaining the machine / soil / crop / weather interactions. Within this network of interactions, soil fauna and soil microorganisms play an important role by forming soil structure, decomposing organic matter, supplying nutrients, controlling pests and plant pathogens etc. but living conditions are affected by mechanical stress through wheeling (Brussaard & van Faassen 1994). Compaction and kneading processes caused by wheels may destroy the pore geometry resulting in an altered habitable pore space as well as changed fluxes and storage of gases, water and matter (Brussaard & van Faassen 1994; Horn et al. 1994).
Nevertheless, wheeling has different consequences for the soil depending, for example, on the tillage system (Blume 1992). Various systems of reduced tillage are in use which may im-

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prove the loadbearing capacity of the soil resulting in different resistances to soil compaction (Ehlers & Claupein 1994).
All these anthropogenic mechanical actions influence the soil fauna. Among the soil fauna Collembola and mites play an important role by controlling decomposition processes particularly through catalysing microbial activity (Hendrix et al. 1986). Heisler & Kaiser (1995) reported decreased microbial biomass and Collembola density with increasing soil compaction and, because of this sensitivity, Heisler (1995) suggested that they would be good bioindicators in this context. Ehrnsberger (1993) summarized the characters which make Collembola and mites generally suitable as bioindicators. They are closely associated with microorganisms, they achieve high densities, are very stationary, have no permanent resistant stages and have short development times.
The effects of different tillage systems and soil compaction on soil microarthropods have been studied in the past (e.g. Friebe 1993; Larink et al. 1995). However, investigations of both factors in combination are still lacking. Furthermore, less is known about the regeneration of microarthropod populations during the growing season after mechanical soil stress. Thus, in the present study, the effects on microarthropods of stress with graded wheel loads in plots tilled to different depths were investigated throughout a growing season.

Materials and Methods

Study Site

The experimental site is located in Thuringia (Germany) near Großobringen in the North of Weimar and is part of the agricultural research area of the Thüringer Landesanstalt für Landwirtschaft (TLL) in Jena. This area is characterized by a quite continental climate with an average precipitation rate of 550 mm/a and a mean annual temperature of 8.2 °C.
The soil type is Schwarzerde from Keuper influenced by loess with a clayey loam texture. The study site was cultivated with summer barley. In the preceeding winter the field was a black fallow. Conventional tillage was practised at the site.

Field experiment

Track by track plots (10 × 70 m) of the field were mechanically compacted by wheeling with graded loads which were uniformly distributed on 2 axis with 4 wheels: 0 t; 2 × 2.5 t; 6 × 5.0 t (wheeling frequency x wheel load). This compaction was carried out on 24 March 1995 when the moisture conditions in the soil reached field capacity. Each plot was divided into two parts which were tilled to different depths (120 mm and 250 mm) using a spading machine. These tillage systems had been used for 7 years. The bulk density was measured between 3 to 11 cm soil depth and was as follows: in the shallow tilled plots 1.26 g/cm^3 (0 t); 1.51 g/cm^3 (2 × 2.5 t); 1.54 g/cm^3 (6 × 5.0 t); in the deep tilled plots 1.32 g/cm^3 (0 t); 1.50 g/cm^3 (2 × 2.5 t); 1.54 g/cm^3 (6 × 5.0 t). Temperature of the same soil depth increased from 10.6 °C (16 May 1995) to 20.2 °C (8 Aug 1995). The soil water content decreased beteen these dates as follows: in the shallow tilled plots from 21.5 to 14.9 wt.% (0 t); 21.8 to 19.2 wt.% (2 × 2.5 t); 22.2 to 16.1 wt.% (6 × 5.0 t); in the deep tilled plots from 13.3 to 18.5 wt.% (0 t); 17.9 to 15.7 wt.% (2 × 2.5 t); 18.1 to 14.7 wt.% (6 × 5.0 t).

Sampling

Sampling was carried out five times between March and August 1995: 23 March (P1), 16 May (P2), 14 June (P3), 17 July (P4) and 8 August (P5). P1 was one day before soil compaction. The last sampling date was directly before harvesting. Eight undisturbed soil cores (diameter 40 mm and depth 150 mm) were taken from each plot on each sampling date. They were taken near the roots within the planting row.
Each soil core was divided into 3 depth fractions of 50 mm. The microarthropod extraction followed the method of Macfadyen (1961). The extraction lasted 10 days, starting at 20 °C with a daily increase of 5 °C up to 45 °C from day 6 to the end. The Mann-Whitney U-Test was used to test for treatment effects.

Results

Total microarthropod population

Before compaction (P1) microarthropod densities in the shallow tilled plots were not significantly different (Fig. 1a). In the unstressed plot (0 t) the total population was 60,000 m^{-2} at the first sampling date. The population increased to 71,000 m^{-2} in May. Then, it decreased in June and July down to 49,000 m^{-2}. From July to August, the abundance increased by 57 % and reached a level of 77,000 m^{-2}. The development of the microarthropod abundance at low soil compaction (2 × 2.5 t) resembled that described but with reduced numbers of individuals on most sampling dates. The numbers of individuals were lower at the very beginning but increased during the course of the experiment up to P5, when more individuals were found in the low stressed plot. High soil compaction had the greatest influence on the microarthropod population resulting in virtually no increase in numbers through the season. The population increased to 40,000 m^{-2} in July and remained at this level in August.
The results for the deep tilled plot without compaction were similar to the shallow tilled plot (Fig. 1b). Here, the highest abundance was 80,000 m^{-2}. Under loading stress, the abundances were less than in the shallow tilled plots. At low soil compaction, the microarthropod population increased to 45,000 m^{-2}. On P3, P4 and P5 the abundances in deep tillage with 2 × 2.5 t loading resembled the data obtained under shallow tillage with 6 × 5.0 t. In the highly compacted plot with deep tillage there were 30,000 m^{-2} at P1. The abundance decreased to 20,000 m^{-2} following compaction and remained at that low level for the following dates. On average, more microarthropods were found in shallow than in deep tilled plots.
Numbers of individuals decreased with increasing soil depth. But this gradient was steeper in the shallow tilled plots than in the deep tilled plots.
In total, 63 % of all microarthropods sampled during the whole growing season on all plots were mites followed by Collembola with 26 %. Pauropoda (4 %) and beetle larvae (2 %) were also found. The remaining 5 % were represented by Protura, Symphyla, Dipteran larvae, Psocoptera and Diplopoda.

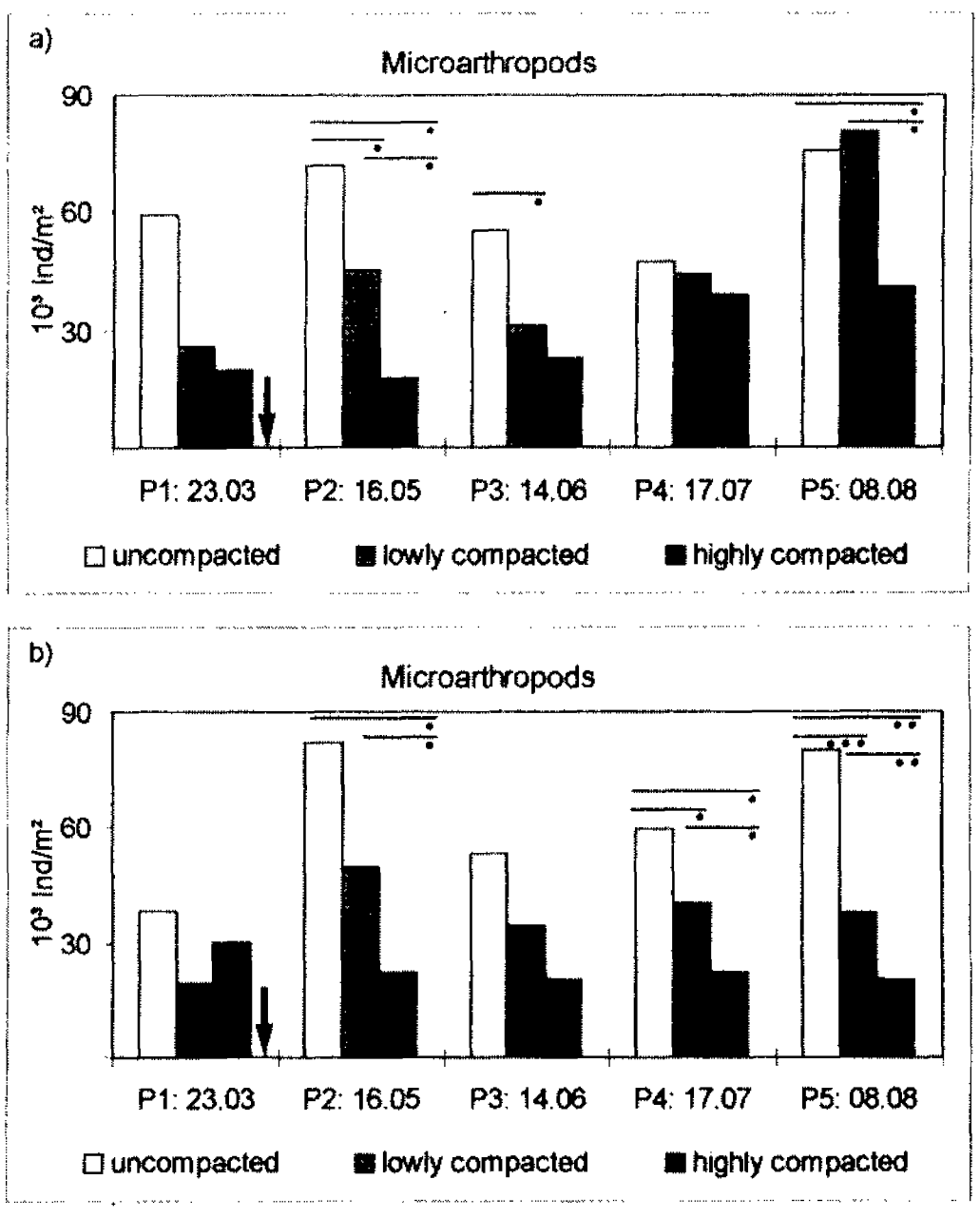


Fig. 1. Abundances of the total microarthropod population in relation to 3 grades of mechanically stressed soil under conventional tillage. The arrow indicates the date of soil compaction by wheeling. *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$. a. Shallow tillage. b. Deep tillage

Collembola

In the uncompacted plot with shallow tillage, the Collembola population increased to 17,000 m^{-2} on the second date, stayed at this level and increased again at the last sampling date to 30,000 m^{-2} (Fig. 2a). With low soil compaction, the abundance first declined but then there was a constant increase to more than 30,000 m^{-2}. In the highly compacted soil the abundance increased on the last sampling date to 8,500 m^{-2}.
The numbers in the deep tilled plots were generally lower (Fig. 2b). During the growing season the abundance of Collembola decreased until P3 and increased again to 21,000 m^{-2} at P5, the same abundance which was found at P1. With low soil compaction and deep tillage the abundance was generally lower, reaching its highest value at P5 with 13,700 m^{-2}. The greatest reduction happened with high compaction as the population decreased at the second date to only 10 %. On the last sampling date the abundance reached nearly 5,000 m^{-2} which is 50 % of the abundance at P1.

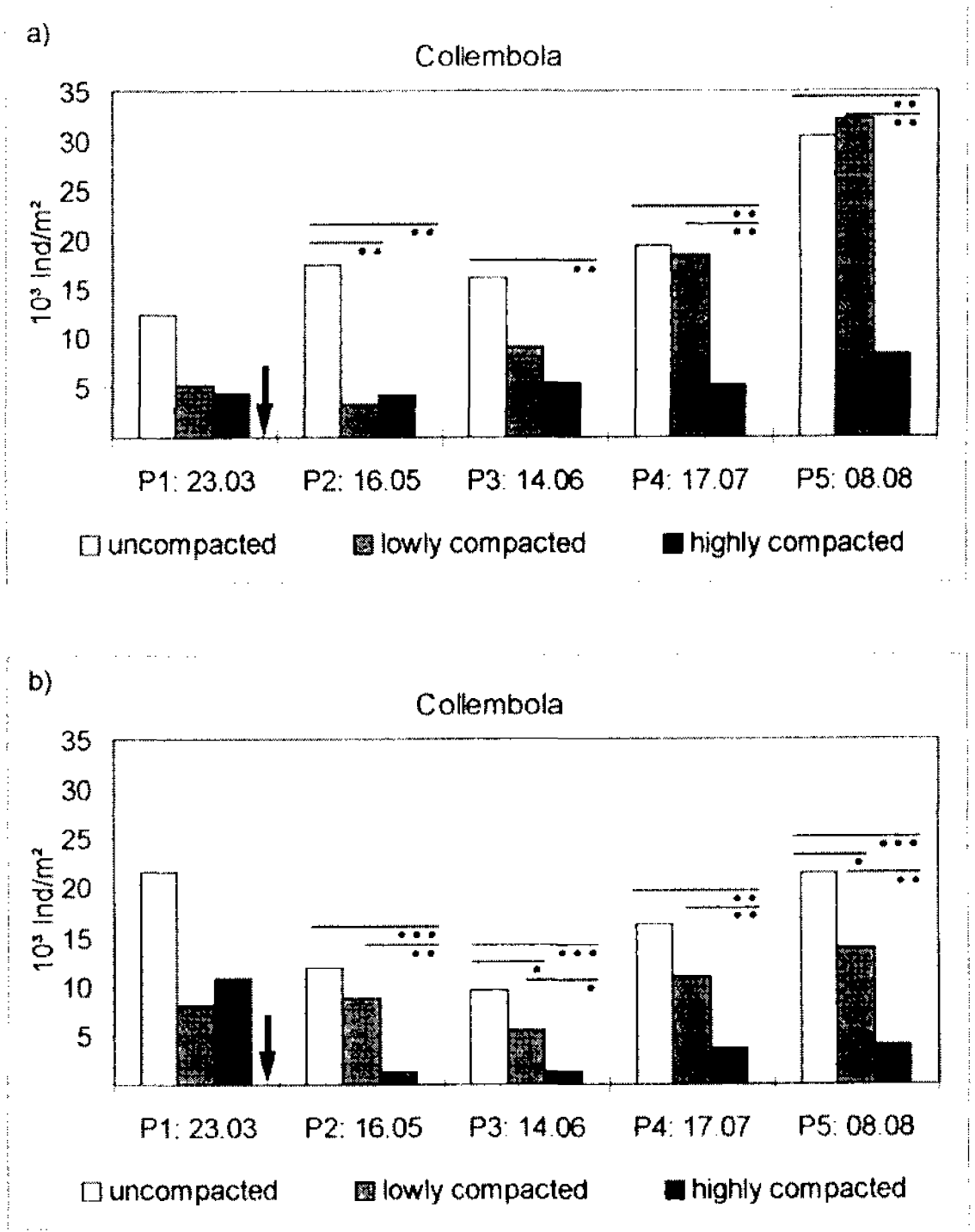
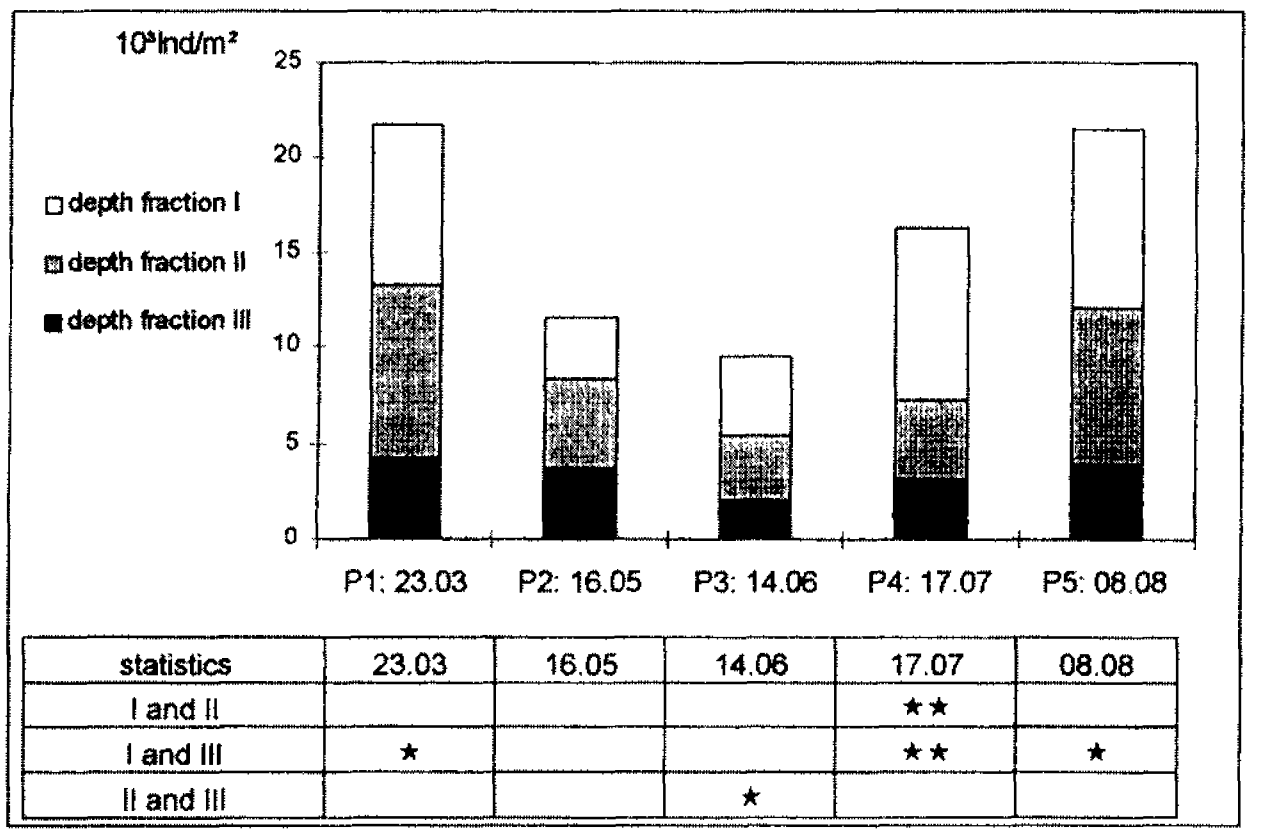


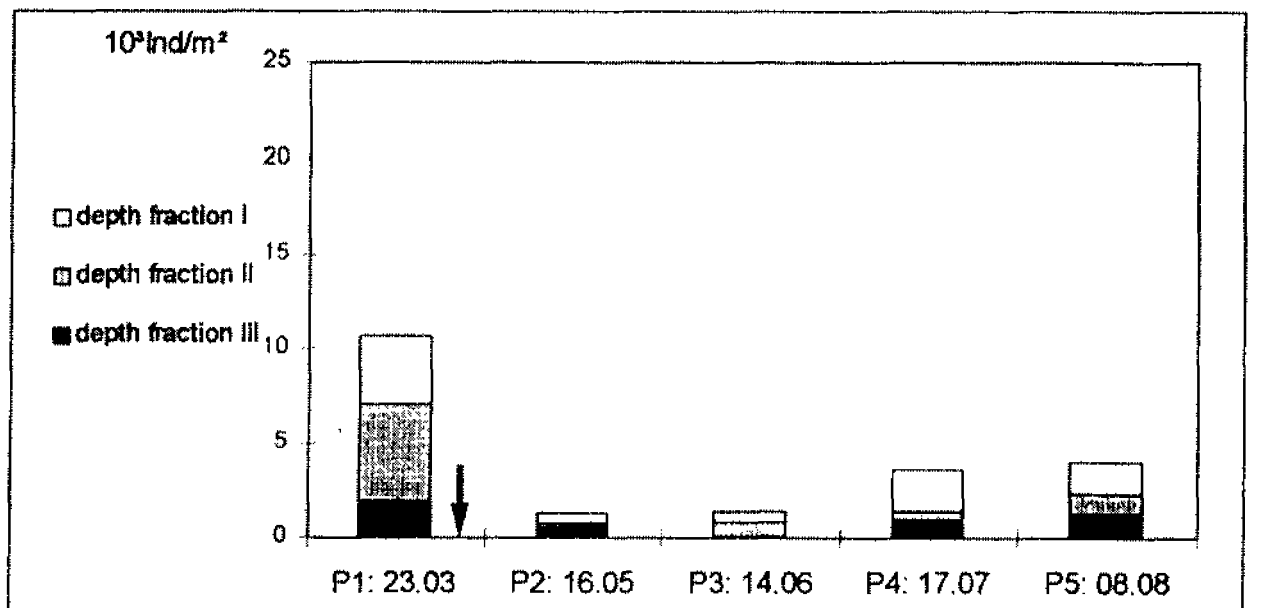
Fig. 2. Abundances of the Collembola population in relation to 3 grades of mechanically stressed soil under conventional tillage. The arrow indicates the date of soil compaction by wheeling. *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$. a. Shallow tillage. b. Deep tillage

With shallow tillage, most individuals were found in the upper soil fraction (0 to 50 mm), which was twice the sum of the lower two fractions. With deep tillage, the Collembola were distributed more uniformly (Fig. 3) with as many in the 50 to 100 mm fraction as in the upper fraction. With low soil compaction, the vertical distribution was hardly disturbed but in the case of the highly stressed soil the influence of compaction was very great (Fig. 4). On the first and second dates after compaction (P2 and P3), the distribution was confused, with an altered relationship among the fractions. This shifting of the populations among the depth fractions at P2 and P3 in the shallow tilled plots may be a consequence of vertical migration. The comparison of the uncompacted with the highly compacted plots shows a recovery of the vertical distribution at P5.



statistics	23.03	16.05	14.06	17.07	08.08
I and II				★★	
I and III	★			★★	★
II and III			★		

Fig. 3. Vertical distribution of the Collembola population among the soil depth fractions 1 (0 to 50 mm), 2 (50 to 100 mm) and 3 (100 to 150 mm) in relation to uncompacted conditions under deep tillage. *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$



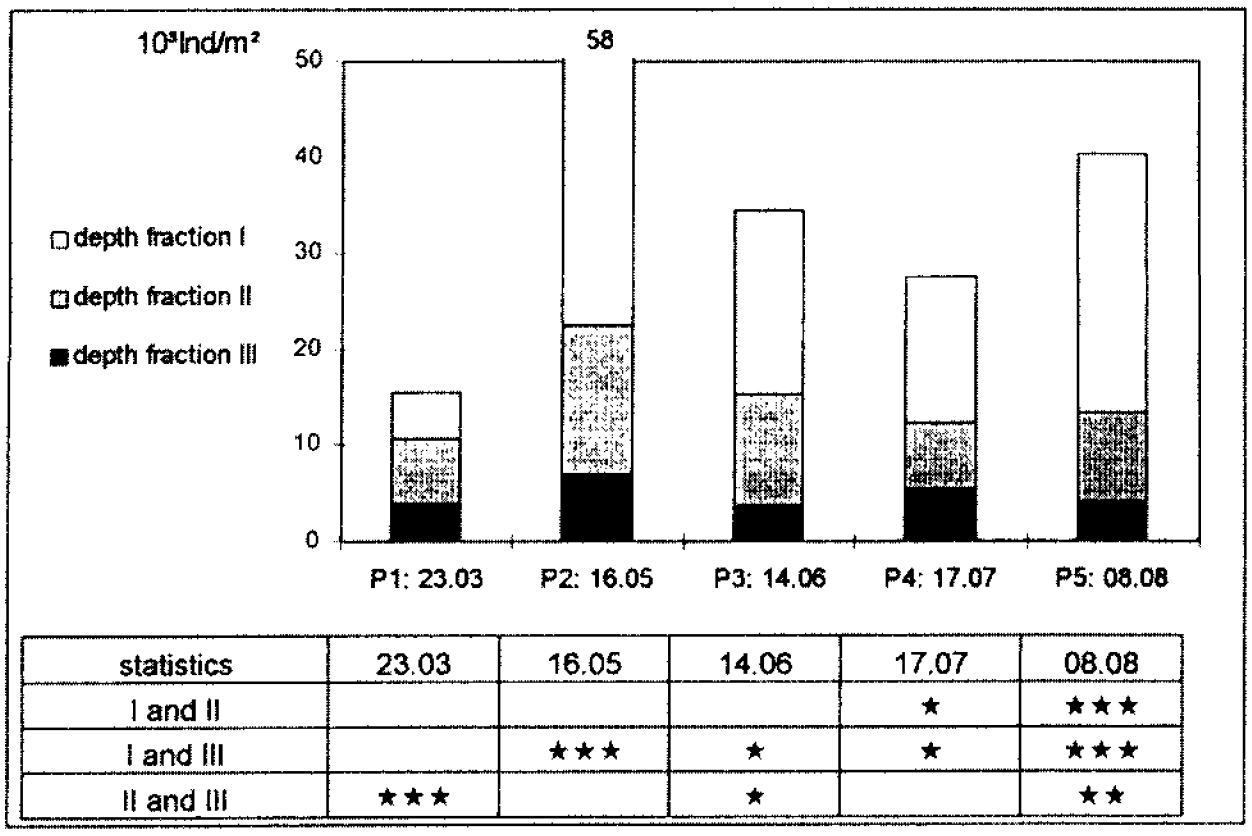
statistics	23.03	16.05	14.06	17.07	08.08
I and II				★★	
I and III				★	★★★
II and III					

Fig. 4. Vertical distribution of the Collembola population among the soil depth fractions 1 (0 to 50 mm), 2 (50 to 100 mm) and 3 (100 to 150 mm) in relation to highly compacted conditions ($6 \times 5{,}0$ t) under deep tillage. The arrow indicates the date of soil compaction by wheeling. *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$

Mites

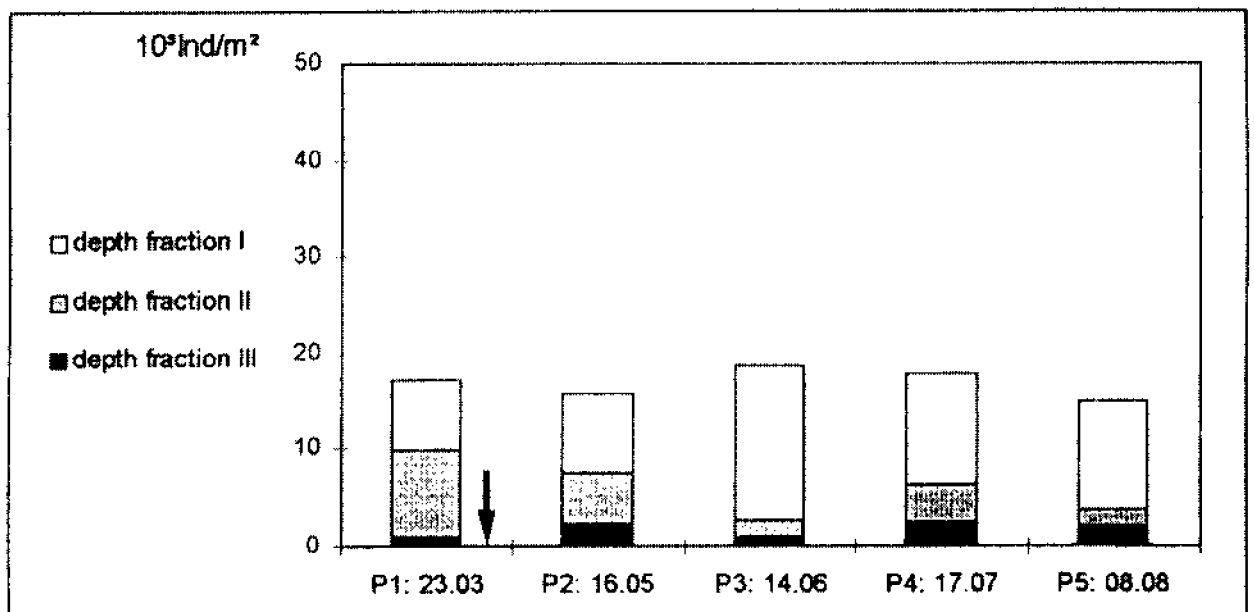
The size of the mite population during the growing season reflects the abundance of the total microarthropod population. But there was one exception at P4 under shallow tillage. Here, the abundances were inverted, with increasing numbers from the uncompacted to the lowly and the highly compacted plot. The effects of soil compaction were more pronounced with deep than with shallow tillage. Generally, mites were less affected by mechanical soil stress than Collembola.

This is also shown in the vertical distribution. In the highly compacted plots (Fig. 6), the vertical distribution was hardly disturbed at P2 because the number of mites was only shifted in favour of the 2 lower soil fractions. From the third sampling date, the mite population was again most abundant in the upper soil fraction (0 to 50 mm), but proportionally more abundant than in the unstressed plots (Fig. 5). As with Collembola, relatively more mites occurred in the upper soil fraction of the shallow tilled plots than in the same fraction of the deep tilled plots.



statistics	23.03	16.05	14.06	17.07	08.08
I and II				★	★★★
I and III		★★★	★	★	★★★
II and III	★★★		★		★★

Fig. 5. Vertical distribution of the mite population among the soil depth fractions 1 (0 to 50 mm), 2 (50 to 100 mm) and 3 (100 to 150 mm) in relation to uncompacted conditions under deep tillage. *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$



statistics	23.03	16.05	14.06	17.07	08.08
I and II			★★★	★★	★★
I and III	★		★★★	★★★	★★
II and III					

Fig. 6. Vertical distribution of the mite population among the soil depth fractions 1 (0 to 50 mm), 2 (50 to 100 mm) and 3 (100 to 150 mm) in relation to highly compacted conditions (6 × 5,0 t) under deep tillage. The arrow indicates the date of soil compaction by wheeling. *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$

Discussion

On average, the abundances in the uncompacted plots of the present study fit in the range given by Tischler (1965) for Collembola (5,000 to 20,000 m^{-2}) and mites (10,000 to 90,000 m^{-2}) in arable fields.

Soil tillage causes direct and indirect effects on the soil (Blume 1992; Ehlers & Claupein 1994). These effects are positive for the soil health when reduced tillage is combined with residue management. In this context, the direct impacts are on the soil itself and affect structure, pore system and loadbearing capacity. In contrast, indirect effects affect transport processes, such as water infiltration and matter translocation, as well as soil biota. In the present study higher microarthropod abundances were found with shallow tillage than with deep tillage. The reason is the accumulation of organic residues in the top soil layer of 120 mm which is the biologically most active part in the soil. In the case of deep tillage (250 mm), the added organic matter is distributed over a more extended range. However, previous test samples of the plots showed hardly any microarthropods deeper than 15 cm for both tillage systems. Furthermore, the wheeling caused more negative effects on the populations in deep tillage than in shallow tillage plots. In this context, Sommer & Zach (1986) point out that the looser

the soil structure, the more sensitive the soil will be to mechanical stress. In the present study, the bulk density increased with increased wheel loads in both tillage systems to nearly the same values. After compaction, the soil stayed more moist in the shallow tilled plots which might have improved the biological activity. No relationship was found between microarthropod abundances and climate conditions such as temperature and rainfall.

According to Bauchhenß (1982), the vertical distribution of microarthropods depends on the distribution and quantity of macropores in the soil profile. Additionally, the continuity of the pores, i.e. a well developed pore network, plays an important role in determining abundance and vertical distribution (Heisler 1993). Soil stress by wheeling not only causes compaction which results in reduced pore space but kneading processes, caused by wheel slip, are important because the pore geometry is destroyed. During wheel slip, bulk density may not increase significantly under wet conditions but the kneading may result in homogenized soil (Horn et al. 1994). Collembola and mites are highly dependant on the pore geometry because most are not able to move soil particles. Didden (1987) demonstrated that compacted soil hampered Collembola migration and had a repellent effect on the fauna when compared to uncompacted soil.

The present study showed that Collembola are more sensitive to soil compaction than mites. This result corresponds to the study of Heisler (1994) who found a decrease in the Collembola population of 60 % and in the Gamasina population (predatory mites) of 30 % in highly compacted wheel tracks. Heisler (1995) suggests both mesofaunal taxa as bioindicators. Mechanical stress leads to a decreased proportion of euedaphic Collembola among the Collembola and an increased proportion of small Gamasina among the Gamasina.

The sensitivity of microarthropods to mechanical stress and the persistence of that stress during the growing season became obvious by studying the development of the populations. At the end of the growing season, the population from a compacted plot reached approximately the same density as the population from an uncompacted plot with the same tillage system. But recovery of the microarthropod population occurred only in the plots with shallow tillage. The Collembola only recovered in the plots with low compaction whereas the mites also recovered in the highly compacted plots. Microarthropods recovered faster in the upper soil fraction (0 to 50 mm) than in deeper fractions. According to Larink et al. (1994) small euedaphic species, which live deeper in the soil, suffer more under soil stress than hemiedaphic or bigger epedaphic species living on the soil surface.

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